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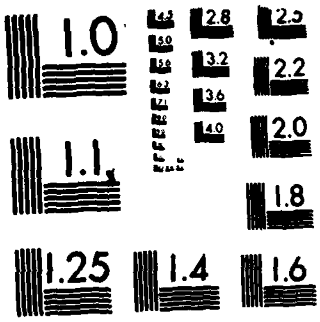

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The soils were usually brighter than the vegetation in the visible region, although some gravelled soils and some gray colored species had similar values. In the visible region, brightness values ranging from 15 to 20 separated most vegetation and soils. Many soil and vegetation surfaces had similar near infra-red (NIR) brightness values.

The NIR:visible band ratios discriminated most soils from the vegetation samples. The soils had NIR;visible ratios less than 2.3, gray and yellow-green colored species had ratios of 2.0 to 7.5 and green vegetation had ratios $>$ 7.5. The ratios of bands from the same spectral region did not discriminate soil from vegetation. Differences in percent cover, leaf area, biomass and senesced foliage affected the visible and NIR reflectance of the plant species. Even so, selected NIR:visible band ratios separated most soil and vegetation samples and differentiated the vegetation by its general color.

DISCRIMINATING VEGETATION AND SOILS USING LANDSAT MSS AND THEMATIC MAPPER BANDS AND BAND RATIOS

Melvin B. Satterwhite
U. S. Army Engineer Topographic Laboratories
Research Institute, Center for Remote Sensing
Fort Belvoir, Virginia 22060

ABSTRACT

Characterizing arid region soils and vegetation conditions from remotely sensed imagery is often limited by the low brightness contrast between soil and vegetation and between different plant communities. The purpose of this study was to determine those Landsat multi-spectral scanner and Thematic Mapper bands and band ratios useful for discriminating soil and vegetation in a semiarid region.

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The NIR:visible band ratios discriminated most soils from the vegetation samples. The soils had NIR:visible ratios less than 2.3, gray and yellow-green colored species had ratios of 2.0 to 7.5 and green vegetation had ratios >7.5. The ratios of bands from the same spectral region did not discriminate soil from vegetation. Differences in percent cover, leaf area, biomass and senesced foliage affected the visible and NIR reflectance of the plant species. Even so, selected NIR:visible band ratios separated most soil and vegetation samples and differentiated the vegetation by its general color.

INTRODUCTION

Describing soil and vegetation conditions from Landsat imagery has traditionally not been easy, particularly when soil and vegetation have low spectral contrast or when there is a small percentage of vegetative cover. Ground level investigations have shown that spectral characteristics of soil and vegetation surfaces are affected by the percentages of soil and vegetation and the reflectance contrast between these components (Colwell, 1974; Satterwhite, et al., 1982). Discriminating vegetation and soil surfaces or monitoring plant growth by remote sensing spectral techniques has relied on spectral differences in carefully selected bandpasses (Knipling, 1970; Colwell, 1974; Richardson and Wiegand, 1977; and Kumar and Silva, 1977).

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Vegetation and soil conditions have been correlated with the ratios of various spectral bands. The better ratios are those calculated from bands that enhance spectral differences between vegetation and soil. Many investigators have used the chlorophyll absorption in the red region and the enhanced spectral reflectance in the near-infrared region (Rouse, et al., 1973; Tucker, 1979). Large variations in soil visible-NIR reflectance spectra can result from variation in soil surface conditions. The spectra of vegetation can be highly variable as well because of differences in pigmentation, structure, leaf area, crown cover and shadows (Satterwhite and Henley, 1982). The spectral characteristics of the plant and soil conditions in semi-arid and arid regions have been studied on a limited basis.

OBJECTIVE

The objective of this study is to evaluate the ground level visible-near infrared reflectance spectra of vegetation and soil surfaces in a semi-arid region for Landsat MSS and Thematic Mapper bandpasses and band ratios that could discriminate these surfaces.

MATERIALS AND METHODS

Reflectance spectra were taken of vegetation and soil conditions at 25 sample sites in northern Nevada. The vegetated surfaces had as near 100 percent cover as was possible. The soil surfaces were devoid of vegetation. Photographs taken at nadir of the samples were used to calculate the percent vegetative cover using a dot counting sampling procedure.

The reflectance spectra were taken in the field with a spectroradiometer system, EG&G model 550/555, over the 400 to 1100nm region in 10nm increments. Measurements were made between 1030 and 1400 hours local solar time on clear cloud free days. Spectral reflectance was calculated as the ratio of the sample's radiance to the radiance of the standard reference target for the same 10nm increment. Halon was used as the standard reference target (Wiedner and Hsia, 1981). The mean brightness values of each target were calculated for the Landsat MSS bandpasses; band 4 (500-600nm), band 5 (600-700nm), band 6 (700-800nm) and band 7 (800-1100nm), and the four Landsat Thematic Mapper bandpasses (TM); TM-1 (450-520nm), TM-2 (520-600nm), TM-3 (630-690) and TM-4 (760-900nm). All brightness values are reported on a 0 to 100 scale. No adjustment of these data was made to approximate the Landsat sensor values.

Correlation coefficients were calculated between the Landsat MSS band pairs and between the Thematic Mapper band pairs (Hewlett Packard, 1980).

Band ratios were calculated for all Landsat MSS band pairs and Thematic Mapper band pairs using Equation 1.

$$\text{Band A / Band B} \qquad \text{Eq. 1}$$

where band A is the longer wavelength bandpass and band B is the shorter.

RESULTS

The plant species, their associated sample number, the number of spectra taken of each species and the general foliage color are given in Table 1. These are dominant and subdominant plant species at each site.

The Landsat MSS and Thematic Mapper band brightness values were calculated from the reflectance spectra taken of 35 soil surfaces and 127 vegetation samples. The soil surface materials varied between the sites: mixtures of sand, silt and clay sized particles; gravels; salt crust; or salt precipitates. The soil brightness values were variable in all MSS and Thematic Mapper bandpasses. The low brightness values were soil surfaces partially or totally covered with dark toned gravels or with some dried moss. The soils with high brightness values had either salt crusts or salts precipitated on the soil particles (figures 1 and 2). The shrub and graminoid species had observable differences in growth stage, canopy cover, height, and plant color. The photosynthetically active plants had low visible brightness values that varied over a narrow range and higher NIR values although these could vary substantially. Senesced foliage had higher visible brightness values but moderate NIR values. The plants with tall dense canopies had low visible and high NIR brightness values while shorter, less dense canopies had slightly higher visible and lower NIR values. The gray-colored species had higher visible and lower NIR values than the green-colored species. The vegetation's maximum visible brightness was about 15 to 20 depending on the bandpass. The soil and vegetation samples can be placed into one of three arbitrary groups based on their visible brightness value: a) soils that have brightness values greater than 20; b) gray and yellow-green colored vegetation that have brightness values ranging from 10 to 20; and c) green colored vegetation that have brightness values less than 10. Some gray or yellow-green colored plant species and some soils had similar visible brightness values.

In the near infrared region, the plant's brightness values varied substantially, with a maximum reflectance near 75 (figures 1 and 2). The NIR brightness values show other vegetative factors were affecting the NIR reflectance, such as pigmentation, structure, multiple leaf layers, or biomass. Soils had NIR brightness values that were similar to many vegetation samples.

The correlations between the band brightness values show that band pairs from the same spectral region, either visible or NIR, were highly correlated for both soil and vegetation; R values >0.90 (Table 2). The soils had high correlation between all visible and NIR bands. Scatter plots of the soil spectral data show the relation between these bands (figures 1 and 2). Low correlations were found between the visible and the NIR bands for the vegetation, R values <0.4. The low correlations indicate vegetative factors had increased the NIR reflectance but had no corresponding effect on the visible reflectance.

The minimum, mean, and maximum band:band ratio values are presented in Table 2 for the total sample and separately for the soil and vegetation. The ratios for the soil targets ranged from 1.0 to 2.3 and were positively correlated. This shows the direct relation between band brightness values and increasing wavelength. For the vegetation samples, the ratios ranged from 0.41 to 1.37 for bands from the same spectral region while the NIR:visible band ratios ranged from 1.19 to 32.3. The NIR:visible band ratios show the greater brightness contrast between the blue or red chlorophyll absorption bands and the NIR bands that is brought about by multiple leaf layers or biomass. The fact that neither the blue nor red band was highly correlated with a NIR band shows the anisotrophic effect of these factors on the reflectance characteristics of vegetation. The Thematic Mapper bandpasses have slightly better correlation and higher visible to NIR contrast than the MSS bandpasses.

The selected band:band ratios are plotted in figures 3 and 4. These plots show the visible:visible ratios and the NIR:NIR ratios could not separate most soil ("o") and vegetation targets ("+") because they have similar ratios. The NIR:visible ratios could separate most soils from the yellow-green and green colored vegetation, but some gray colored species were not distinct from some soils.

DISCUSSION

The Landsat MSS or Thematic Mapper sensors have predetermined those spectral regions in which soil and vegetation analysis must be made. Therefore, the soil and vegetation must have sufficient differences in these spectral bands or the ratios of these bands if they are to be differentiated.

Spectral data presented here show the vegetation and soil discrimination is dependent, in part, on the reflectance contrast and the spectral region. Visible brightness levels can separate many soil and vegetative surfaces, but some soil surfaces had brightness values similar to those of some plant species. The photosynthetically active vegetation had visible brightness values ranging from 3 to 20, in which the green vegetation had lower values and the gray vegetation had higher values. The maximum visible brightness value for vegetation was 15 to 20 (figure 1 and 2). Most soils had values greater than 20, which would permit using a visible band to separate most soil and vegetation surfaces. Some dark-toned gravelled soils had brightness values <20 and could be confused with some gray colored shrub species. This is significant because these gray colored shrub species frequently occur on the gravelled dark-toned soils. The NIR bands were not useful by themselves for separating vegetation and soil because of little or no brightness contrast between many plant species and the soils. The use of a single bandpass for differentiating soil and vegetation is possible for some vegetation and soil surfaces, but apriori knowledge of the general vegetation and soil condition would be needed. Even so, some soils and vegetation could have no or little brightness contrast and would not be separable.

The soil spectral brightness varied directly with wavelength over the 400 to 1100nm spectrum. The soil's brightness was never lower than the preceding bandpass. This was true for soils with salt crust or salts precipitated on the surface, for silt or silty clay textured soils, and for soils with a mantle of dark-toned gravels. The low reflectance contrast between bands meant that any band:band ratio would be small. The ratios ranging from 0.1 to 2.3 were indicative of soil.

The vegetation had substantial brightness contrast between the visible and NIR regions, but had low brightness contrast within a region. The ratio of 2 visible of 2 NIR bands produced values <2.0 which were similar to the soil ratio values for the same bands (Table 2). The vegetation brightness value had no direct relation with increasing wavelength because of the chlorophyll absorption in the blue and red bands. The blue or red bands were inversely related to the NIR bands and they had low correlations. These relations show the anisotrophic effects of vegetative factors, e.g., biomass and leaf area, on the visible and NIR brightness values. These factors increased the NIR brightness values but had little or no effect on the visible brightness values, except as might be associated with increased vegetative cover (figures 3 and 4). The increased NIR brightness resulted from multiple reflectance from multiple leaf layers within the plant canopy (Meyers, et al., 1968; Satterwhite and Henley, 1982). These absorption and reflectance relations provide a basis for using NIR:red and NIR:blue ratios for separating soil and vegetation surfaces. The vegetation NIR:visible band ratios ranged from 2 to 32, while the soil ratios were <2.3.

The brightness values were variable between species and within a species, depending on several vegetative factors. Pigmentation affected the brightness contrast between the visible and NIR bands. The green colored vegetation (numbers 12, 13, 14 and 15) had low blue and red brightness values, slightly higher green values and high NIR band values. The gray colored vegetation (numbers 3, 5, 7 and 10) had sightly higher visible band brightness values but lower NIR brightness values than the green vegetation.

Plant growth stage also affected the visible-NIR brightness values. The two alfalfa surfaces with the lowest NIR values consisted of 90 percent cover and 100 percent senesced foliage. These visible and NIR band brightness values for senesced vegetation were similar to the values of some soil conditions.

The major differences in the NIR band brightness values were related to biomass and leaf area differences for a plant species. Alfalfa (#15) shows a large range of NIR brightness values but a small range of visible values. The high NIR brightness values were associated with alfalfa >50cm tall and >90 percent cover; while moderate NIR brightness values were associated with dense alfalfa 30cm tall and >90 percent cover. The visible brightness values of these samples were about the same, 3 to 5 percent.

Discriminating vegetation and soil targets could not be done readily using the ratios between band pairs from the same spectral region, either visible or NIR. Although the band brightness values were highly correlated, R values >0.80, these ratios were small, <2.3, and essentially the same for the vegetation and soil (figures 3 and 4). Good separation of most vegetation and soils was achieved using the NIR:visible band ratios. Those visible and NIR bands with high reflectance contrast produced NIR:visible ratios that generally separated the soil and vegetation into three groups: a) soil, with ratios less than 2.3; b) gray and yellow-green colored vegetation, with ratios of 2.0 to 7.5; and c) green colored vegetation, with ratios greater than 7.5. The green vegetation was most easily discriminated from the soils because of the high NIR:blue and NIR:red brightness contrast. The NIR:visible ratios did not discriminate between vegetation and soils with low visible to NIR contrast, e.g., dried moss, Suaeda sp; Atriplex confertifolia, senesced vegetation, and gravelled soils because their ratios were nearly the same. The low NIR:visible brightness contrast is one reason most band ratios would probably not discriminate soils and vegetation on the Landsat imagery. The NIR:visible ratios apparently ordered the vegetation by the color, percent cover, biomass, and leaf areas. The large ratios were associated with green vegetation with high percent cover and high biomass, and the low ratios were associated with low cover and low biomass.

In arid regions, the soil and vegetation surfaces can vary substantially, as can their spectral contrast. The discrimination of soil and vegetation by their brightness contrast in a single band may be possible but some soil and plant species may have similar spectral characteristics. Different assemblages of soil and vegetation and variable percentages of vegetative cover in the soil-vegetation mosaic can bring about similar band brightness values in the Landsat image.

CONCLUSIONS

1. The visible bandpasses can separate most soil and vegetation surfaces: a) brightness values less than 15 to 20 indicate vegetation; b) brightness values greater than 15 to 20 indicate soil; c) some gray colored vegetation and dark toned soil surfaces can have similar brightness values.

2. Many soil and vegetation surfaces had NIR brightness values that were similar in magnitude and range.

3. The NIR:visible band ratio differentiated most soils and vegetation and to some extent two vegetation groups: a) soils had NIR:visible ratios less than 2.3; b) gray and yellow-green colored vegetation had NIR:visible ratios of 2.0 to 7.5; c) green colored vegetation had NIR:visible ratios greater than 7.5.

4. The visible:visible ratios or the NIR:NIR ratios did not differentiate most soil and vegetation conditions.

5. The vegetation reflectance spectra were affected by the percentages of plant cover, senesced foliage, leaf area, and biomass. These factors affected the visible and NIR spectra differently and the band ratios calculated from the visible and NIR bands.

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Table 1
Soil and Vegetation Samples

Sample Number	Sample	Number of Spectra	General Color
1	Soil	36	variable
2	Moss	3	gray to black
3	*Artemisia tridentata*	11	gray
4	*Suaeda* sp.	2	dark blue-green
5	*Atriplex confertifolia*	23	gray
6	*Allenrolfea occidentalis*	6	grayish green
7	*Salix* sp.	4	gray
8	*Sarcobatus vermiculatus*	31	yellow-green
9	*Chrysothamnus nauseosus*	8	blue-gray/green
10	*Tamarisk* sp.	1	dark green
11	*Distichlis stricta*	7	dark green
12	*Typha* sp.	2	dark green
13	*Carex* sp.	5	dark green
14	Grass	6	green
15	Alfalfa	18	green

Table 2
Summary Statistics for Landsat MSS and Thematic Mapper Band Ratios

Target	MSS Band Pairs*						Thematic Mapper Band Pairs**					
	5/4	6/4	7/4	6/5	7/5	7/6	2/1	3/1	4/1	3/2	4/2	4/3
All Targets (n=162)												
minimum	0.52	1.11	1.11	1.04	1.04	1.00	0.24	0.10	1.22	0.41	1.10	1.05
maximum	1.32	11.5	15.5	19.8	27.1	1.59	2.55	2.19	30.9	1.37	14.7	32.3
r-value	0.99	0.36	0.16	0.03	-0.06	0.92	0.97	0.96	-0.03	0.99	0.01	-0.06
Soil (n=35)												
minimum	1.07	1.11	1.11	1.04	1.04	1.00	1.10	1.16	1.22	1.05	1.10	1.05
mean	1.21	1.36	1.52	1.13	1.26	1.11	1.27	1.49	1.76	1.17	1.38	1.10
maximum	1.32	1.58	1.90	1.25	1.64	1.36	1.41	1.71	2.27	1.28	1.66	1.37
r-value	0.99	0.97	0.93	0.99	0.91	0.98	0.99	0.97	0.93	0.9[illegible]	0.96	0.98
Vegetation (n=127)												
minimum	0.52	1.43	1.75	1.19	1.45	1.00	0.94	0.94	1.92	0.41	1.52	1.38
mean	0.75	3.68	5.00	4.46	6.00	1.31	1.69	1.41	8.35	0.86	4.49	6.38
maximum	1.42	11.5	15.5	19.8	27.1	1.66	2.55	2.19	32.3	1.37	14.7	32.3
r-value	0.97	0.00	-0.27	-0.24	-0.41	0.96	0.89	0.79	-0.33	0.94	-0.25	-0.43

* MSS 4 (500-600nm); MSS 5 (600-700nm); MSS 6 (700-800nm); MSS 7 (800-1100nm)
** TM-1 (450-520nm); TM-2 (520-600nm); TM-3 (630-690nm); TM-4 (760-900nm)

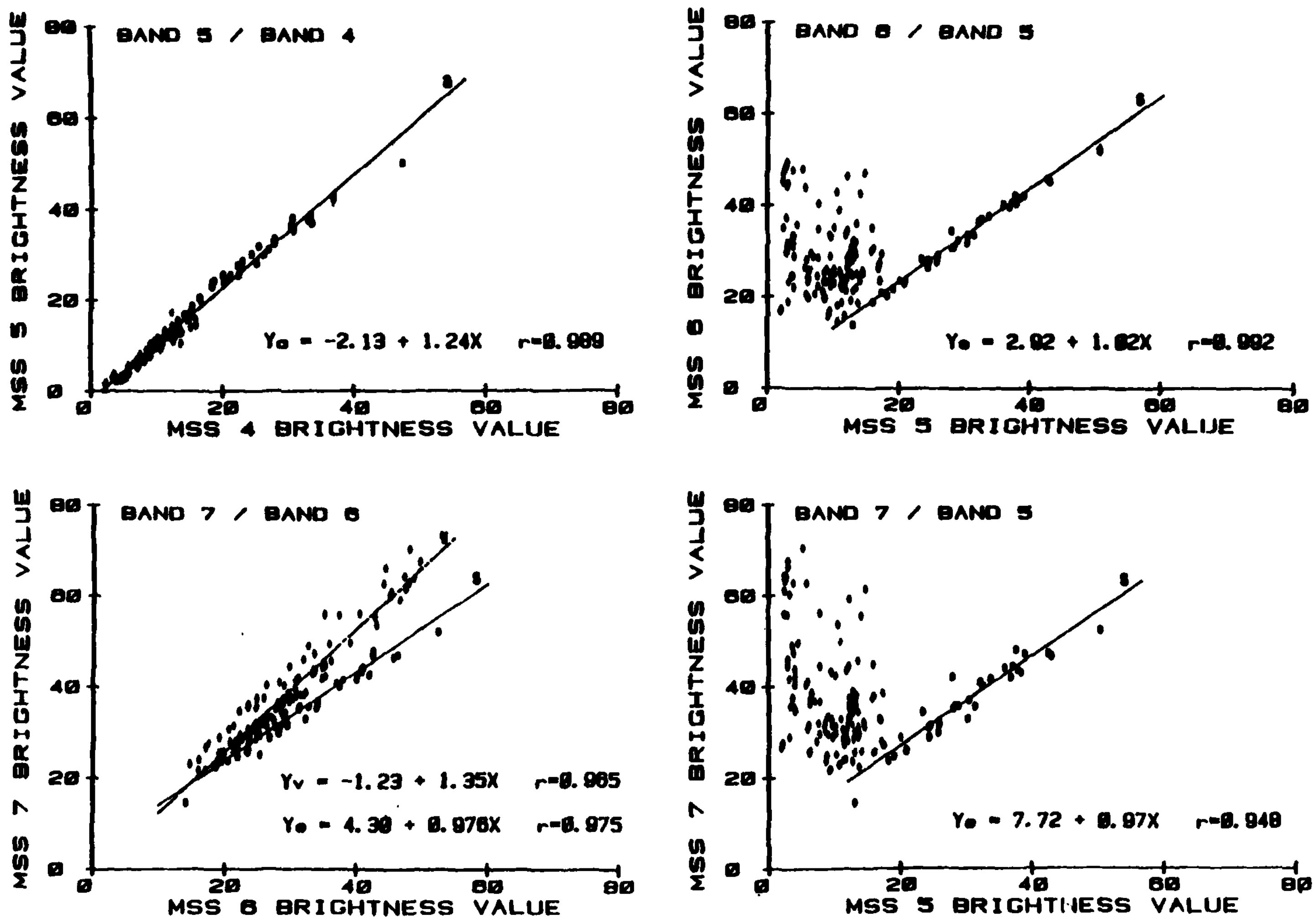

FIGURE 1. SOIL (O) AND VEGETATION (+) BRIGHTNESS VALUES IN LANDSAT MSS BANDS.

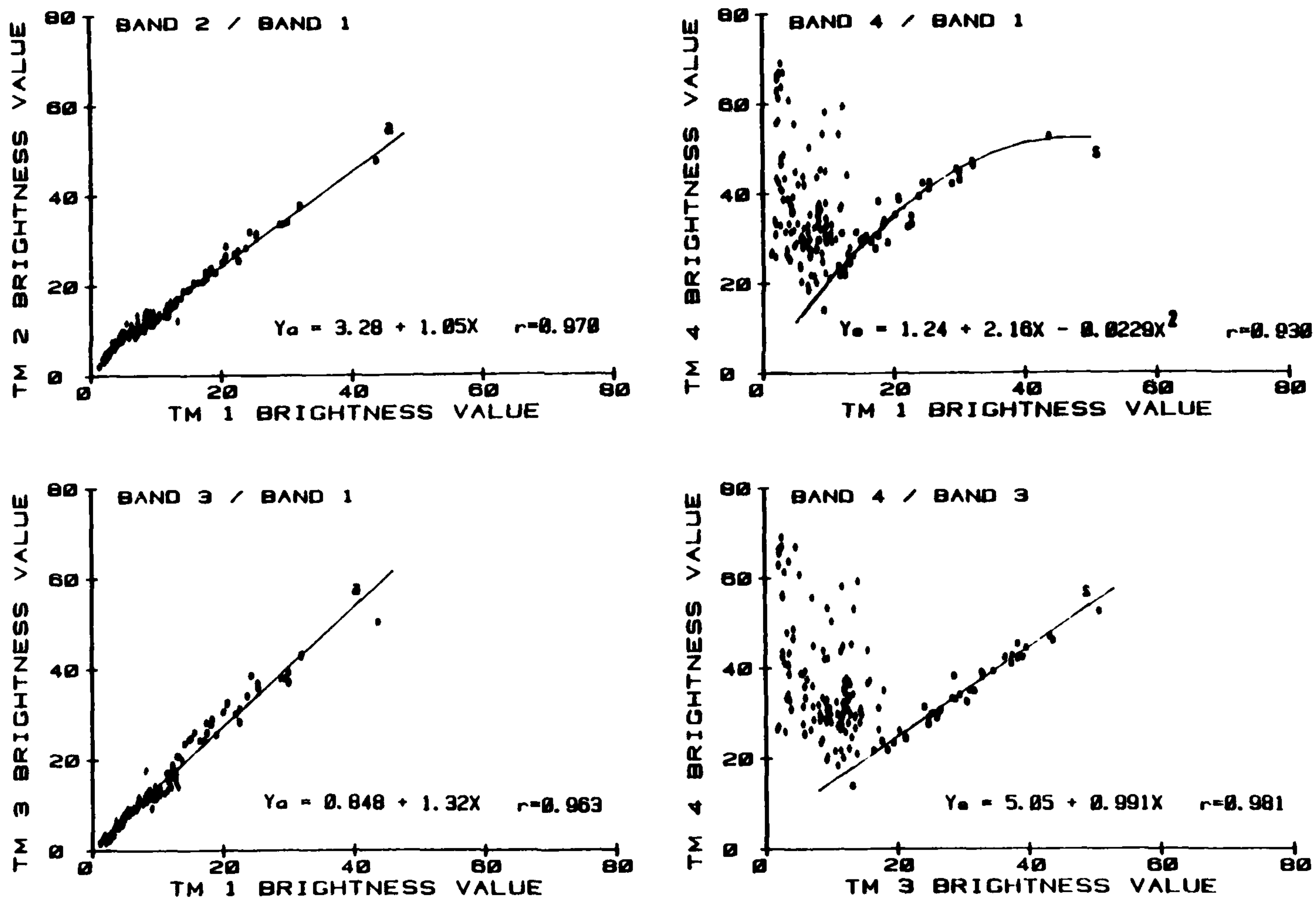

FIGURE 2. SOIL (O) AND VEGETATION (+) BRIGHTNESS VALUES IN LANDSAT THEMATIC MAPPER BANDS.

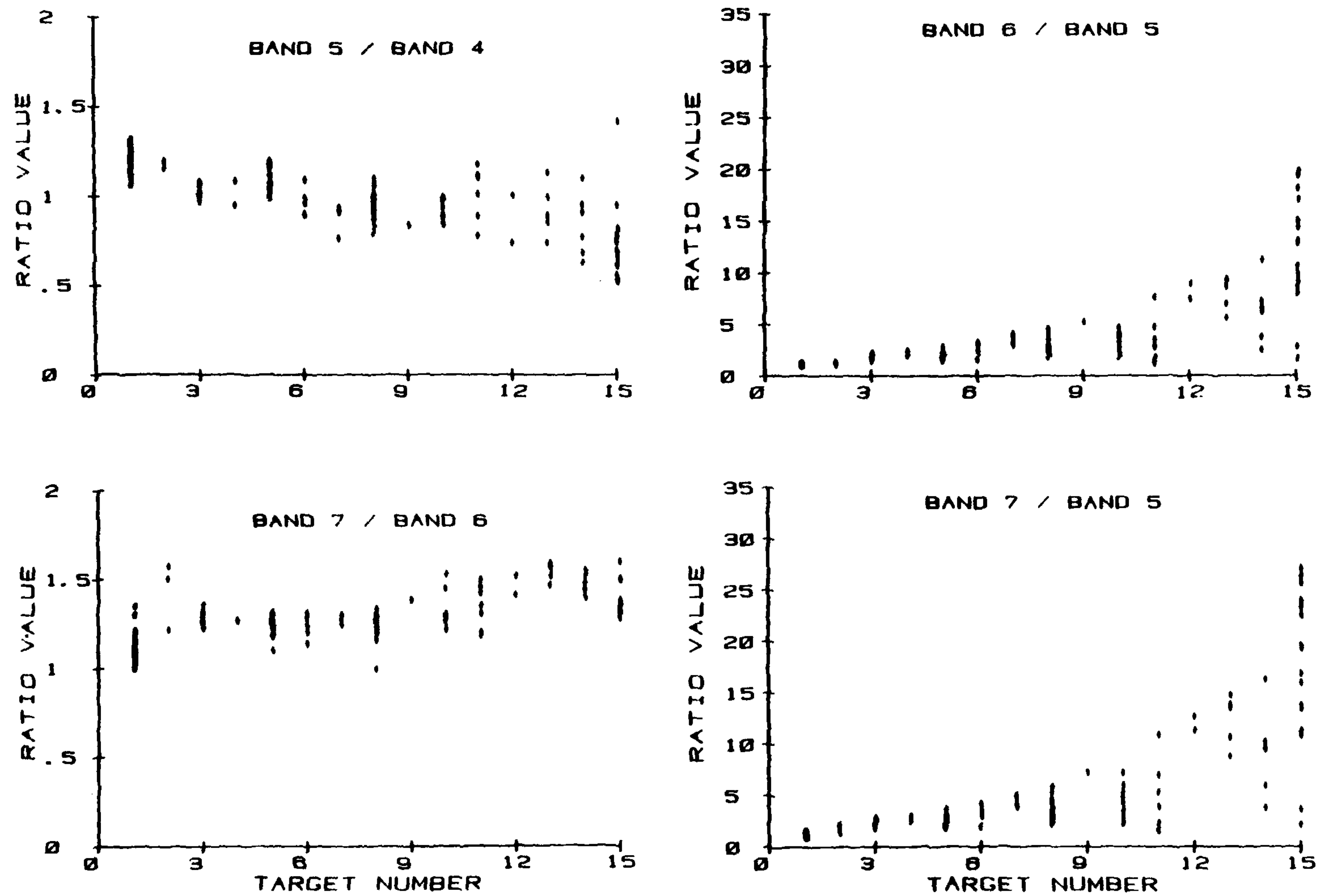

FIGURE 3. SOIL (O) AND VEGETATION (+) RATIOS FOR SELECTED LANDSAT MSS BANDS.

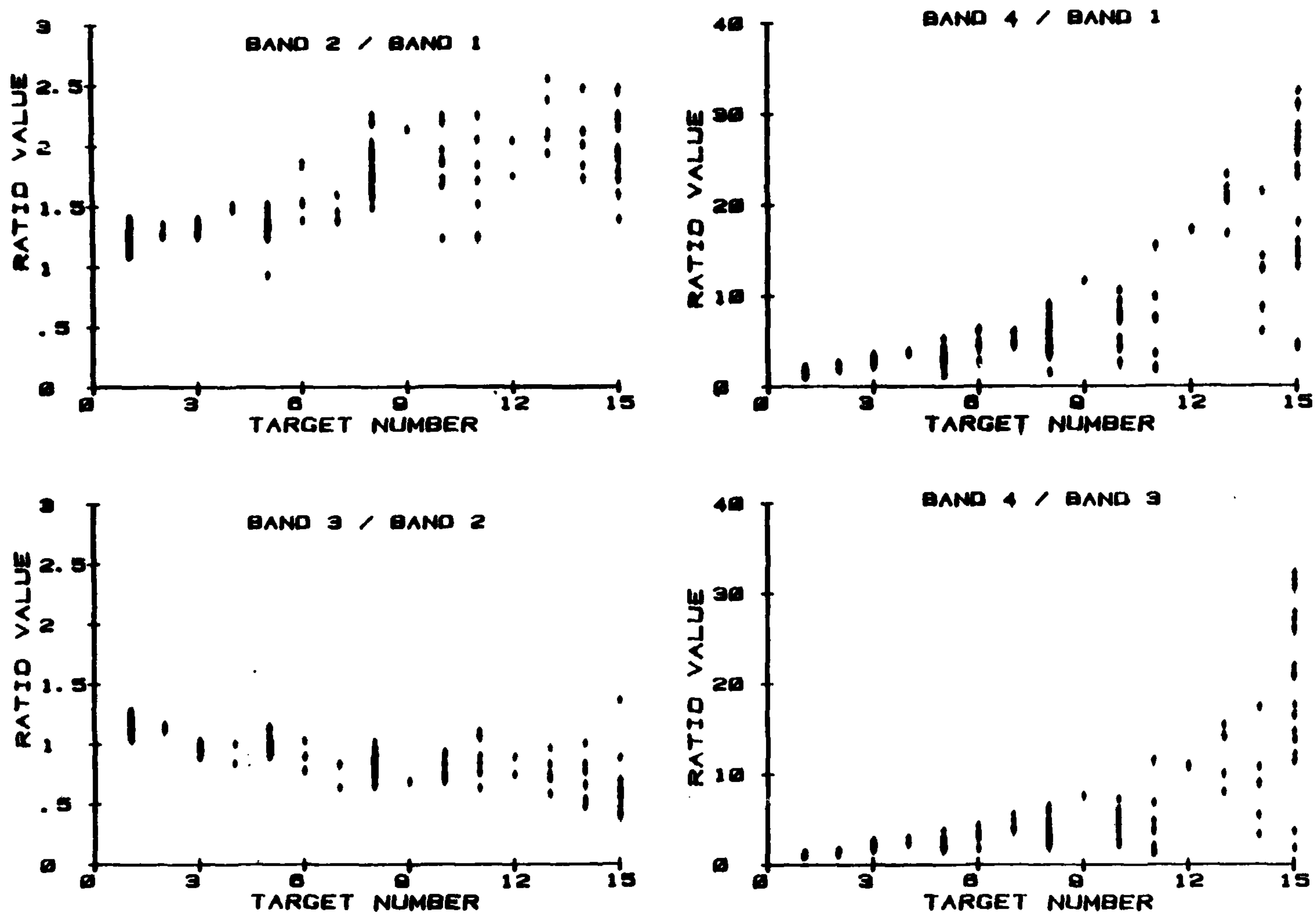

FIGURE 4. SOIL (O) AND VEGETATION (+) RATIOS FOR SELECTED LANDSAT THEMATIC MAPPER BANDS.

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